

Design study of 10kW photovoltaic DC/DCBoost converter

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Abstract. This paper focuses on the maximum power point tracking control of photovoltaic (PV) power generation systems to improve the efficiency of solar energy utilization. Through extensive research of domestic and international literature, several classical control strategies are compared and analysed, and finally the variable step conductance increment method is selected as the basic algorithm of the solution. In this paper, the simulation model of PV power generation system based on DC-DC circuit is established by using MATLAB/simulink software, and Boost circuit is used for designing, which solves the problems of slow tracking speed and unsatisfactory tracking effect existing in the traditional circuit. The paper conducted a comparative analysis of the simulation output by comparing the perturbation observation method, the conductivity increment method and the variable step size conductivity increment method, and evaluated their performance in terms of stability, adjustment time, tracking speed and accuracy under changing light conditions, and found that the variable step size conductivity increment method has better results in tracking speed, accuracy and adjustment time than the traditional method. This study can improve the power generation efficiency of photovoltaic arrays, which is of great significance in promoting the development of renewable energy technologies and the use of clean energy.

Keywords: boost circuit, MPPT, perturbation observation method, conductance increment method.

1. Introductory

In the context of the national strategic decision of "double carbon", solar energy stands out in the field of new energy by virtue of its permanence, cleanliness and flexibility, and has the development prospect of large-scale application [1]. In the pursuit of economic growth, the depletion of resources and environmental pollution have always brought negative impacts on people's lives. Dual-carbon goals and the construction of resource-saving, environmentally friendly society cannot be separated from the development and application of new energy, the introduction of new energy into the field of energy generation has become an inevitable trend. In recent years, with the continuous improvement of photovoltaic technology, the installed capacity is also a record high every year. In order to play the maximum benefit of PV arrays, it is necessary to keep the maximum power output of PV arrays, therefore, the study of maximum power tracking is particularly important [2].

Currently, photovoltaic (PV) power generation is a cleaner and more sustainable structure that is widely used in microgrids, household photovoltaic storage power generation, and photovoltaic power plant systems. Photovoltaic panels convert solar energy into electrical energy, but their output DC energy voltage, power, and current are not stable enough due to the characteristics of the photovoltaic array itself and the operating environment. Therefore, tracking analysis of PV array output is required.

In photovoltaic power generation systems, maximum power point tracking (MPPT) control is commonly used to improve the photovoltaic conversion efficiency of the system [3]. Literature [4], [5] improved the traditional MPPT algorithm by using uncertain inference method and conductivity integration method elimination according to the output characteristics of PV array, respectively. At present, many scholars at home and abroad propose a variety of MPPT based on group intelligence optimization algorithms, such as the immune firefly algorithm, artificial bee colony algorithm, ant lion algorithm, bacterial foraging algorithm, grey wolf algorithm, particle swarm algorithm, etc., the above algorithms are able to track the maximum power, but there are some degree of use of the place of restriction, the convergence of the late convergence of the speed of the slow, the loss of energy, the complexity of the functional implementation of the problem is not easy to adjust and so on [6].

In order to propose an effective control strategy to improve the tracking accuracy and energy utilisation efficiency of photovoltaic power generation, this paper adopts a conductivity increment method using variable step size to improve the tracking control with simple structure and fewer parameters. The effectiveness and feasibility of this algorithm is also verified by comparing the circuit built by MATLAB simulation modelling with the traditional perturbation observation method and conductance increment method.

2. Circuit Design

2.1. Circuit parameter design

In Boost circuits, the control signals of the switching tubes need to be adjusted according to the input voltage to ensure the stability of the output voltage. The circuit boosting process requires attention to static accuracy and dynamic performance indicators, which are related to the circuit design as well as the control strategy.

The structure of the PV system mainly consists of PV array, detection device, DC-DC converter, MPPT control module, PWM module and load (resistance value of R) [7]. In this paper, Boost boost chopper circuit is used as the main circuit of the PV DC/DC converter, Boost switching converter in the boosting process of the sudden change in the size of the load, the input voltage of the sudden rise or fall of external high-frequency interference, etc., the control system can quickly and stably make the feasibility of adjustment. The specific topology of the main circuit is shown in Figure 1 below.

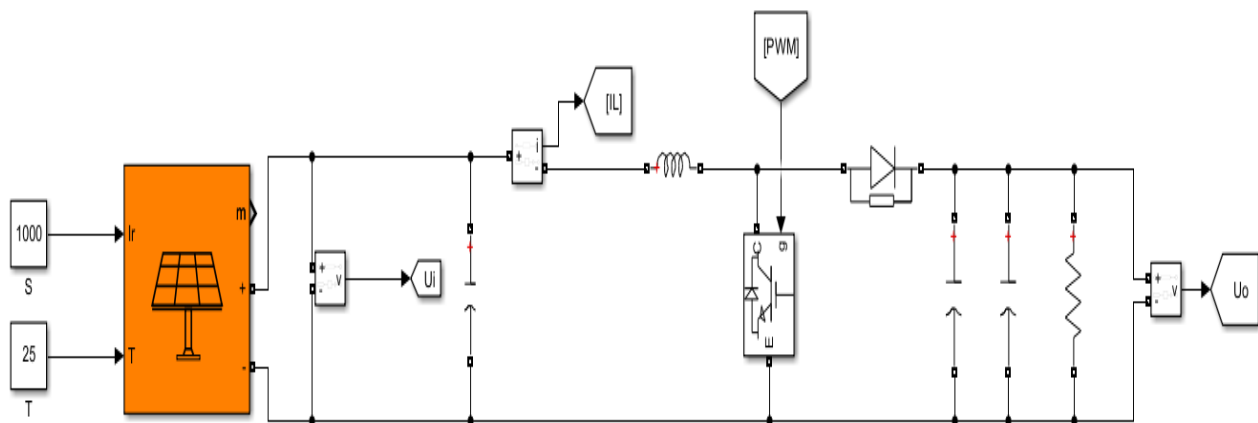


Figure 1. Topology of the main circuit simulation

The circuit diagram shows that the circuit works in the CCM (continuous conduction mode) state. Combined with the actual engineering, a front filter capacitor is added in front, which can filter out the low-pass noise very well. At the same time, we added a diode at the front end to ensure that the current can only be conducted in the forward direction. We improved the Boost circuit, using two capacitors in parallel instead of one of the capacitors. This increases the total capacitance, reduces the equivalent resistance, improves the response speed and stability of the system, reduces the ripple of the circuit due to the presence of parasitic resistance, and optimises the performance and functionality of the system by connecting the capacitors in parallel in a reasonable manner. Especially for the converter we designed, the key is to ensure the stability and response speed of the system, which can better meet the design requirements.

For the selection of power electronics, the design output power of 10kW, combined with the requirements of this paper selects IGBT as the switch of the main circuit, and at the same time, according to the output and circuit requirements to design the IGBT and load parameters.

Relationship between output voltage and input voltage

$$U_o = \beta U_i = \frac{1}{1-\alpha} U_i \quad (1)$$

$$\beta = \frac{T}{t_{on}} \quad (2)$$

$$\alpha = 1 - \beta \quad (3)$$

$$\frac{U_o}{U_i} = \frac{1}{1 - D} \quad (4)$$

Output Current:

$$I_o = \frac{P_o}{U_o} \quad (5)$$

Load Resistance:

$$R_l = \frac{U_o}{I_o} \quad (6)$$

Output side capacitance:

$$C = \frac{U_o DT}{R \Delta U_o} = \frac{I_o DT}{\Delta U_o} \quad (7)$$

Combined with the design requirements and the actual situation, the circuit parameter data and requirements are shown in Table 1 below.

Table 1. Design parameter list of DC-DCBoost converter

notation	Description of symbols
Rated output power (Po)	10kW
Input voltage (Ui)	500V
Output voltage (Uo)	800V
Switching frequency (fs)	5kHz
Inductor current ripple factor (I%)	6 percent
Rated output power (Po)	10kW
Light intensity (S)	1000cd
Duty Cycle (D)	0.375
Opening time (ton)	0.075ms
Filter capacitance (C)	$2.8125 \times 10^{-6} \text{ F}$
Output side capacitance (C1, C2)	$1.01 \times 10^{-4} \text{ F}$
Inductance (L)	$3.64 \times 10^{-2} \text{ H}$
Load resistance (R1)	64Ω

2.2. Modelling and simulation of photovoltaic cells

The P-V curve of a PV cell is the curve of the relationship between the output power and voltage of a PV cell under a certain determined light intensity and ambient temperature, which plays an important role in system analysis and is an important basis for studying the principle of MPPT [8]. PV array MPPT is actually an optimisation process with duty cycle D as the regulating variable, maximizing the actual output power as the goal, and with multi-peak characteristics, so a suitable optimization algorithm is required [9].

After building the circuit model, the control circuit is used to control the IGBT and then the PV circuit. In the following section, the control of Boost Boost circuit by MPTT is discussed. The simulation is analysed by comparing the perturbation observation method, the conductance increment method and the variable step size conductance increment method to explore the comparison.

2.3. Fundamentals of MPPT control for PV systems

When the environmental parameters of the PV array are fixed, there exists a fixed maximum power point P_{max} in the output characteristic curve, at which time the operating voltage and current are U_m and I_m respectively. However, the actual external environment is constantly changing, making the power of the PV array cannot always be at the maximum point, so it is necessary for the MPPT technology to actively respond to the changes in the surrounding environmental parameters to find the optimal operating state of the PV array. The MPPT controller converts the voltage and current generated by the PV array into a control signal through the control strategy and then transmits it to the DC/DC circuit to finally realise the regulation of the output power. The MPPT controller converts the voltage and current generated by the PV array into control signals through the control strategy, and then transmits them to the DC/DC circuits to finally realise the regulation of the output power.

The DC/DC converter is essentially a DC chopper circuit, which is capable of converting DCs to each other and achieving dynamic matching of loads. In this paper, a Boost circuit with higher conversion efficiency and meeting the design requirements is used as the main circuit, and an IGBT is chosen as the fully controlled switch with a period of T .

In the topology, in order to maintain a stable voltage flow through the inductor and the load R , it is necessary to select larger values for L and R . When the switch is in the on state, V_1 and L form a loop, which makes the current of L increase continuously and turn into the charging state, while the capacitor C and the load R form a loop, which makes the capacitor C turn into the discharging state. When the switch is in the cut-off state, the current of the inductor L decreases, which makes L turn into a discharging state, at this time, V_1 and L together with the power supply to the load, and the capacitor C turns into a charging state. The voltage on both sides of the load is greater than V_1 to achieve the purpose of boosting the voltage. The circuit diagram of the IGBT in the conduction and cut-off state is shown in Figure 2.

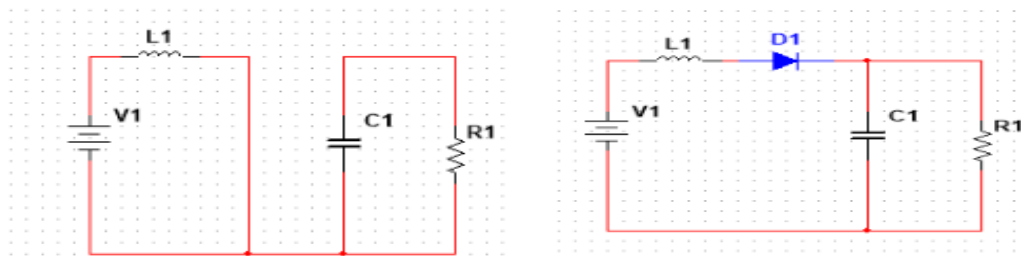


Figure 2. Schematic diagram of Boost circuit in different states

Based on the above parameters and topology, the principle of maximum power tracking of PV system based on Boost circuit is constructed. Photovoltaic cells are greatly affected by temperature and light in the environment. PV cells are connected in series-parallel 4×4 in this paper.

2.4. Disturbance observation method

The perturbation observation method (P&O) is one of the more widely used traditional algorithms, the essence of which is that since there is only one MPP in the P - V curve of a uniformly illuminated photovoltaic cell, firstly, the output power before adding the perturbation is calculated, and then a fixed-step perturbation is applied to the voltage to perturb the output power to change it, and then the power before and after the perturbation is compared, and based on the resulting comparison results, the switching tube duty cycle is adjusted according to the comparison result, so that the PV cell operates near the MPP. The specific optimisation principle is shown in Fig. 3.

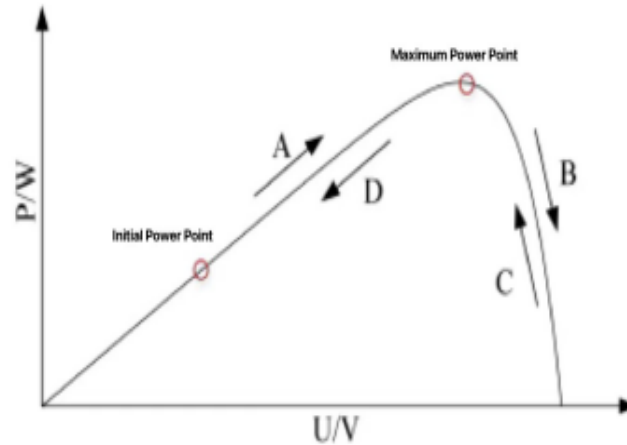


Figure 3. Schematic diagram of the perturbation observation method

According to the simulation model as shown, it can be seen that the MPPT is implemented using the perturbation observation method when the selector switch is 1. Overall structure of the perturbation observation method circuit is shown in figure 4.

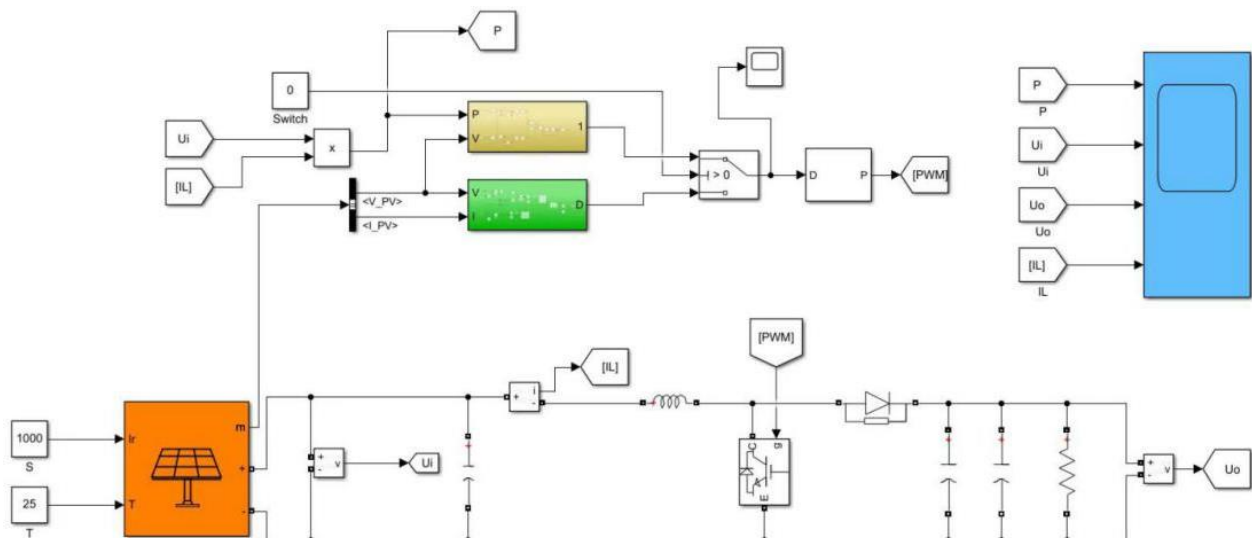


Figure 4. Overall structure of the perturbation observation method circuit

2.5. Conductivity increment method

The incremental method of conductance (INC) is an MPPT method summarized from the P-V relationship curve of PV cells under uniform light, which uses the continuous and conductible single-peak characteristic of the P-V curve to calculate the rate of change of the output current and voltage, and to judge whether it is necessary to apply a perturbation to change the current output power. This method has a more stable performance than the perturbation observation method, and the misjudgement phenomenon is small.

The conductance increment method of regulation is greatly optimized compared to the perturbation observation method, which can radically reduce the impact of the misjudgement phenomenon. The operating state of the PV cell is judged according to different stages, and thus a positive or negative perturbation is judged to be applied to the output voltage.

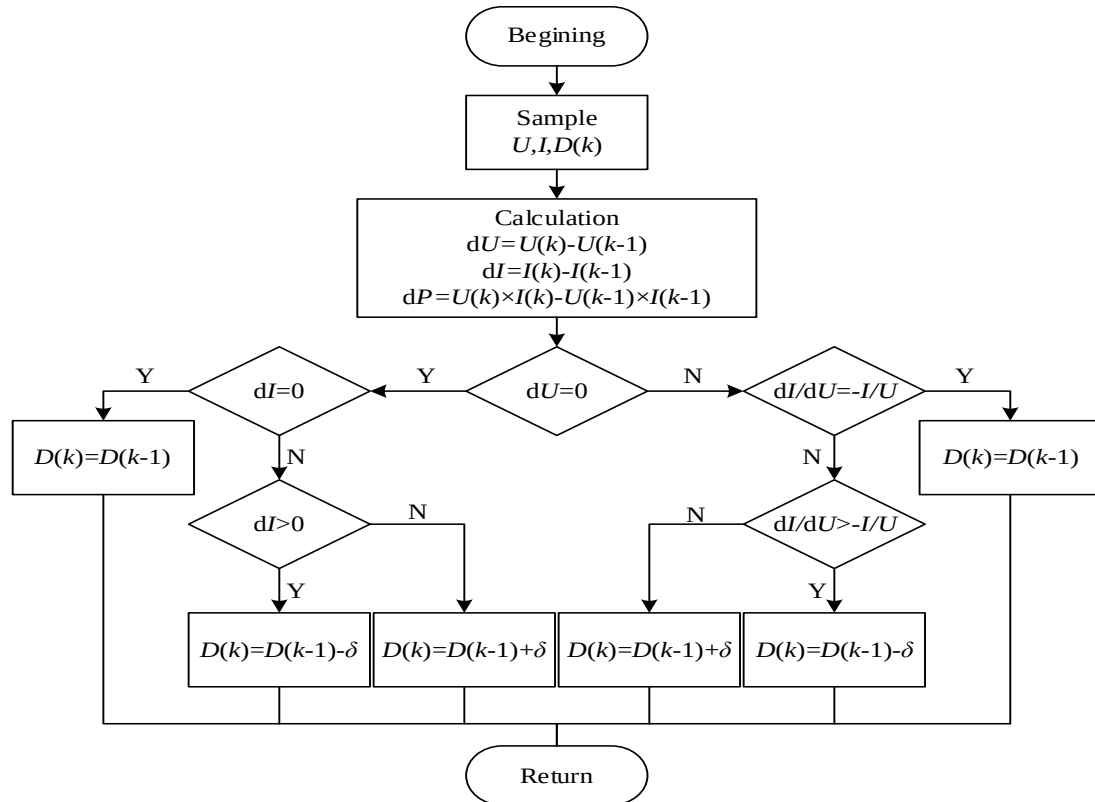


Figure 5. Control flow chart of conductivity increment method

According to the simulation model in Fig. 5, it can be seen that the MPPT is implemented using the conductance increment method when the selector switch is 0.

2.6. Variable step conductivity increment method

Combined with the principle of the variable step conductance increment method, the code can be written. In the process of writing the code, attention should be paid to the duty cycle to limit, to prevent the output waveform of the circuit has a large ripple, high volatility, resulting in stability is also not good enough, as shown in the figure 6, for the variable step conductance incremental method flowchart.

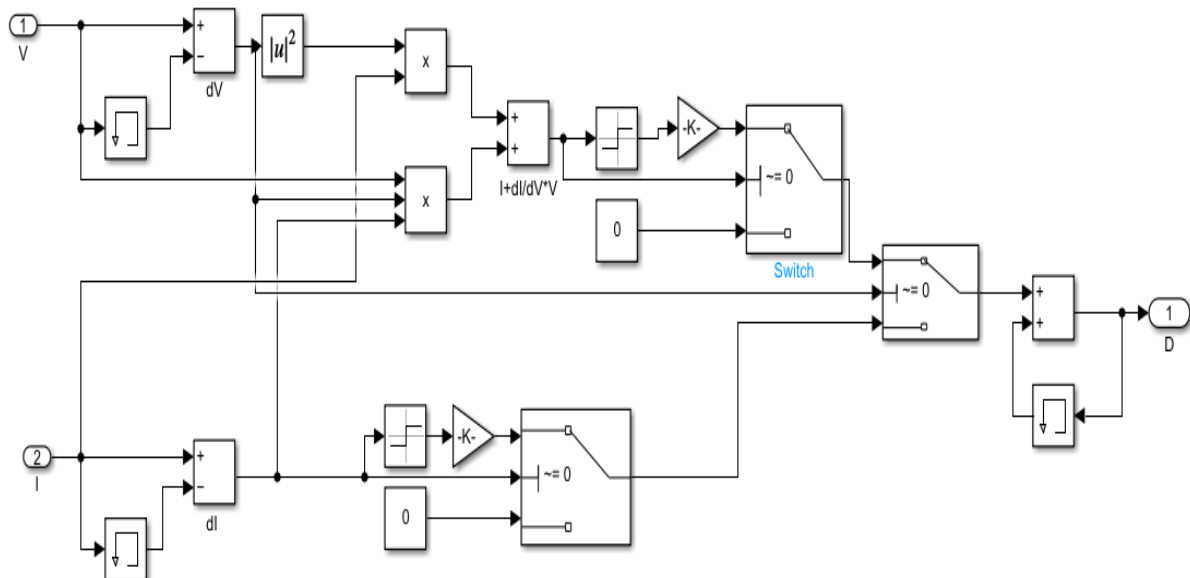


Figure 6. Control flow chart of variable step conductivity increment method

The circuit for the conductivity increment method is shown in Figure 7 below.

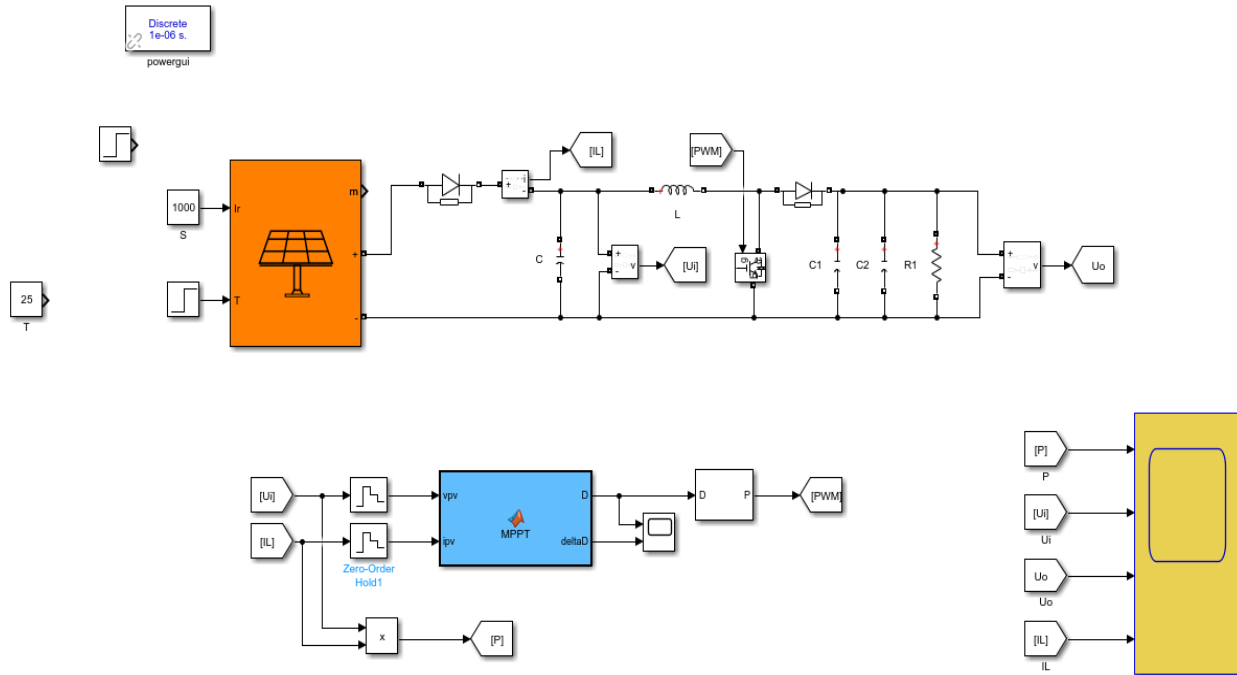


Figure 7. Conductance increment method code circuit diagram

3. Analysis of simulation results

3.1. Comparison of MPPT waveforms from different methods

Based on the above established model, we used MATLAB/simulink to run the simulation model and set the run time to 0.5s due to the fastness of the model.

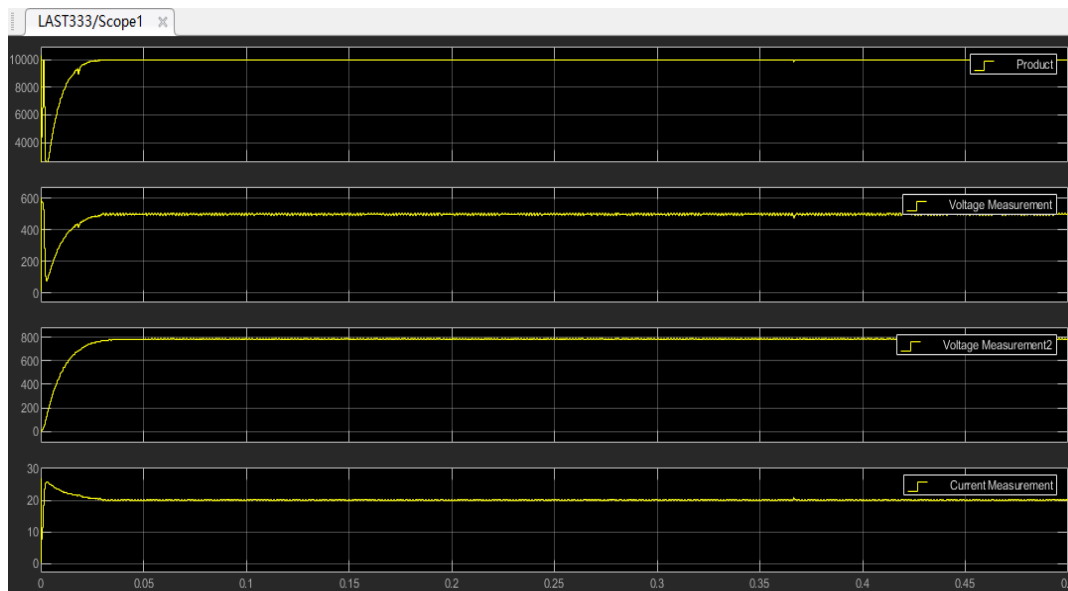


Figure 8. Waveforms of the variable step conductance increment method based on a run time of 0.5s

As can be seen from the Fig. 8, all three simulations are better. The circuit diagrams of the three methods are able to reach stability in about 20ms, and at the same time the overshoot is low enough to meet the requirements. However, for the perturbation observation method, its waveform is more stable and faster, but its power is slightly lower than 10kW, about 0.2kW; its inductor current steady state error is larger, about 20.9 A. The conductance incremental method is able to achieve more stable.

For the circuit diagram of the variable step size conductance increment method, its waveform is more stable with less ripple and better rapidity.

For the above three methods, their inductor current ripple coefficients are 3%, 5.8%, and 2%, respectively; and their steady state speeds are 25ms, 40ms, and 18ms, respectively. it can be obtained from the comparison that the variable step conductance incremental method is more effective than the other two methods.

3.2. Tracking effect under changing light intensity

The factors affecting the PV output characteristics are the outside temperature T and the light intensity S , respectively [10]. For varying light intensity, the tracking speed and tracking are similar for all three. The waveform diagrams are analysed below as an example of the circuit implemented by the variable step conductance increment method.

We kept the temperature 25°C constant and varied the light intensity to 1200 cd and 800 cd at $t = 0.2\text{ s}$. The waveforms are plotted Fig. 9 and 10:

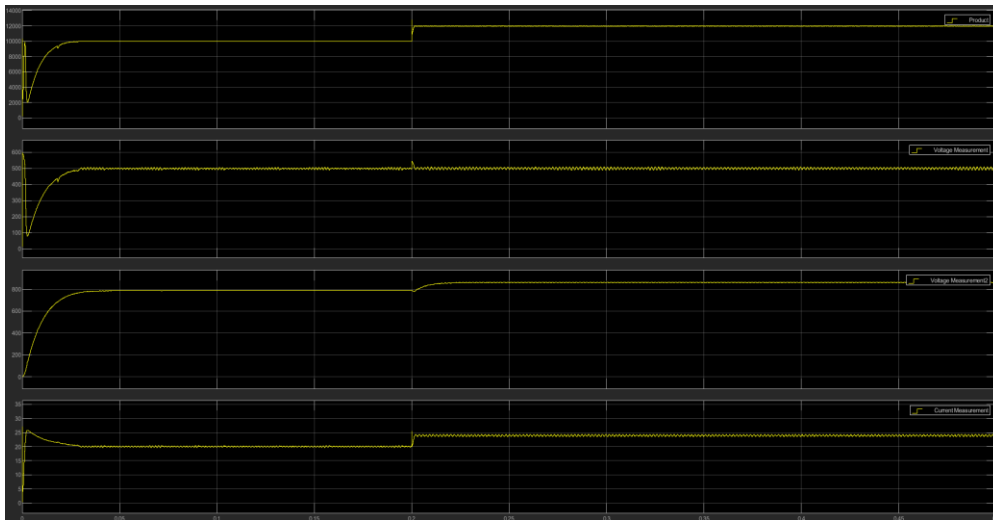


Figure 9. Light intensity changes from 1000 cd to 1200 cd in 0.2s.

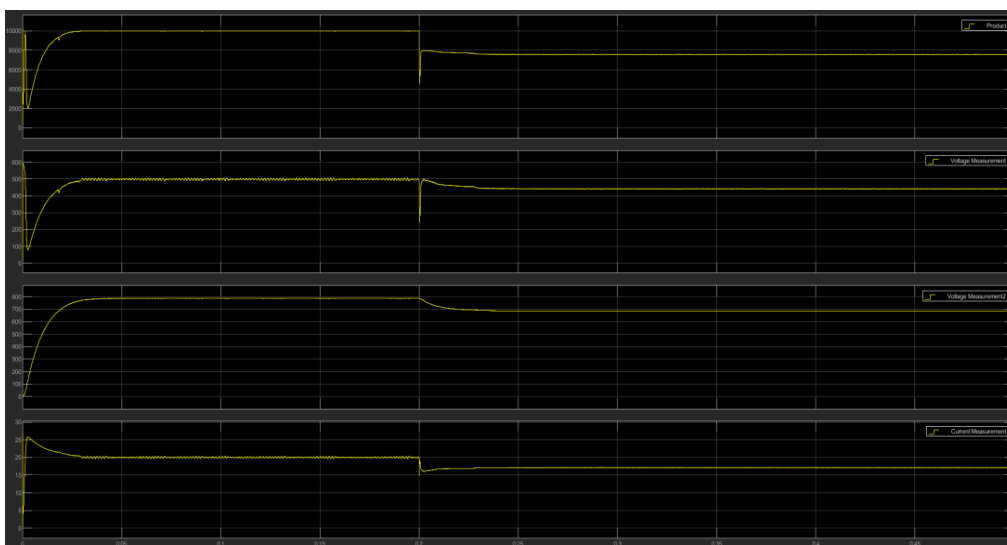


Figure 10. Light intensity changes from 1000 cd to 800 cd in 0.2s.

Observation of the image analysis shows that the waveform after the step can reach stability in 2ms, 30ms respectively, the inductor current ripple coefficient is 3.75%, 0.058% respectively, the output power is about 12kW and 8kW respectively. according to the waveform observation, in the

change of the light intensity, its Y_i will be able to maintain a very good tracking speed and ripple coefficient.

4. Conclusion

To study the principle of PV MPPT technology, the Boost circuit is built as a DC converter circuit through MATLAB/simulink simulation, and the PV system simulation model is established. Overview and simulation of centralised commonly used MPPT control algorithms, constant voltage structure is simple, but only applies to the case of fixed environmental parameters; perturbation observation method algorithm design process is simple, but power fluctuation is large, and the phenomenon of misjudgement is serious; conductivity incremental method is fast tracking speed, wide range of applicability, and compared with other traditional algorithms in the steady state accuracy and the tracking speed at variable illumination has a relative advantage, but the actual application of system sensor. Meanwhile, we implement the variable step size conductivity incremental method, which is better than the classical conductivity incremental method.

Through the running analysis of the simulation model and observing the circuit waveform diagram, the variable step conductance increment method can get a more optimal solution by changing the step length, and the optimal solution can be obtained quickly and accurately by changing the duty cycle and limiting the constant tracking, while the inductor current ripple coefficient of the variable step conductance increment method is small, and the steady state accuracy can meet the requirements. The model has a wide range of application, low requirements, and is suitable for temperature and light changes; better sensitivity, high accuracy, short adjustment time, and stability.

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